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Unified Wet Deposition Data Summaries for North America
Data Summary Procedures and Results for 1980-1986

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16. ABSTRACT

This paper presents a general framework for data quality assessment of annual and seasonal wet deposition data summaries. Primary consideration has been given to (1) using data from regional or national networks with established quality assurance programs and documented network operation protocols, (2) assessing regional representativeness of each site, (3) determining quantitative data completeness measures used to define data completeness levels, and (4) explicitly stating the calculation procedures used to compute precipitation-weighted average concentrations and total deposition. The procedures described are applied to data collected in 1984 by the CAPMoN, APIOS, MAP3S, NADP/NTN, and UAPSP monitoring networks in North America and annual sulfate summaries are reported. It is recommended that the concepts of site representativeness levels, data completeness levels, and overall data quality levels be adopted by others and routinely be reported along with a data summary. Further work on assessing accuracy and precision to accompany the data quality levels is required.

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UNIFIED WET DEPOSITION DATA SUMMARIES FOR NORTH AMERICA: DATA SUMMARY PROCEDURES AND RESULTS FOR 1980–1986

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Abstract—This paper presents a framework for data quality assessment of annual and seasonal precipitation chemistry data summaries. Consideration has been given to (i) using data from regional or national networks with established quality assurance/quality control programs and well documented network operation protocols, (ii) assessing regional representativeness of each site, (iii) determining quantitative measures to define data completeness levels, and (iv) documenting the calculation procedures used to compute precipitation-weighted mean concentrations and wet deposition amounts. The procedures described here are applied to data collected from 1980 to 1986 by five major acid deposition monitoring networks in North America and examples of annual sulfate deposition summaries are reported. It is recommended that the concepts of site representativeness, data completeness and overall data quality levels be adopted by the user community and routinely be reported along with a data summary. Further work on assessing accuracy and precision to accompany the data quality levels is recommended.

Key word index: Wet deposition, unified wet deposition database, ADS, data screening.

INTRODUCTION

In response to a need of regional scale acid deposition modelers, the Unified Deposition Database Committee (UDDC) was formed under the Canadian Federal Provincial Research and Monitoring Co-ordinating Committee and the National Acid Precipitation Assessment Program (NAPAP) in the U.S.A. to develop a unified and up-to-date data set of seasonal and annual average concentrations and wet deposition amounts of sulfate and nitrate in eastern North America. Fundamental to the effort was the need to define data screening and calculation procedures to allow the merger of data from a number of networks. Each data summary was to be accompanied by an overall data quality rating, based primarily on considerations of data completeness and site representativeness. Detailed reports on the Committee's work are available from the UDDC (1985, 1986) and are summarized by Lusis *et al.* (1986).

The needs for an integrated, centralized data base of precipitation chemistry data and for methods to establish the compatibility of data from multiple networks have been emphasized in workshops (Gibson, 1980; Pack and Shepard, 1983). In the past each network manager or researcher used his own method to compute seasonal and annual summaries, with limited attention given to compatibility with other network data. This led to problems in interpreting, e.g. spatial and temporal patterns in deposition (Barrie and Hales, 1984) and in evaluating acid deposition models (Voldner *et al.*, 1988; MOI, 1982). Evaluation of regional acid deposition models requires a well documented deposition data set, which has been compiled using clearly defined data screening and calculation procedures. An indication of the quality of the data, and hence the error/uncertainty in a data point, is essential to allow interpretation of model performance. An indication of the data quality is also needed for assessing the relationships between emissions and deposition, historical trends in deposition and the effects of atmospheric deposition on the terrestrial and aquatic ecosystems.

The procedures, described in this paper, were developed primarily to meet the needs of researchers concerned with regional scale acid deposition models. Although it is recognized that alternative methods for data screening, calculation of seasonal and annual averages and totals, and for assignment of data quality levels may be required by other users, the Committee believes the framework established here provides a common basis for future precipitation chemistry summaries.

The UDDC's procedures, which incorporate ideas and concepts suggested by other researchers (e.g. MAP3S/RAINE, 1982; Voldner *et al.*, 1984), have

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gained acceptance among the user community. They are used routinely in the Acid Deposition System (ADS), the central repository for acid deposition data in North America (Sweeney and Olsen, 1989). A subset of the procedures has been incorporated into the National Atmospheric Chemistry Database (NAtChem) system in Canada (NAtChem, 1987) and by the National Acid Deposition Program National Trends Network (NADP/NTN) (NADP, 1985, 1986a, b). Screened data, meeting at least the minimum quality criteria, formed the basis for analysis of spatial and temporal variability in concentration and deposition of acidifying species (e.g. Alvo and Voldner, 1989; NAPAP, 1987; Seilkop and Finkelstein, 1987) and were used in the International Sulfur Deposition Model Evaluation (Voldner *et al.*, 1988; Clark *et al.*, 1989).

In this paper we first discuss the general requirements for preparing a data summary. We then describe each factor that is used in evaluating the quality of the data and the criteria for judging each factor. We show the methods for computing the seasonal and annual data summaries and for assigning the data quality levels. We provide an illustration of summaries available from ADS and finally give an overview of the quality of wet deposition amounts for the period 1980–1986. The data originate from the five major networks, which are routinely reporting data of ADS. The networks in the U.S. are: the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), the Multi-state Atmospheric Pollution and Power Production Study Precipitation Chemistry Network (MAP3S/PCN), and the Utility Acid Precipitation Study Program network (UAPSP, formerly EPRI/SURE); and in Canada—Canadian Network for Sampling Precipitation (CANSAP) and the Air and Precipitation Monitoring Network (APN), which were in 1983 replaced by the Canadian Air and Precipitation Monitoring Network (CAPMoN), and the Acid Precipitation in Ontario Study daily and cumulative networks (APIOS-D and APIOS-C).

GENERAL FRAMEWORK FOR DATA SUMMARIZATION

Data summarization begins with the acceptance of each contributing network's objectives, protocols, quality assurance procedures, data handling, validation and reporting procedures and ends with the preparation of the summary accompanied by documentation. Here we focus on the data summarization process that occurs after the individual samples have been validated and reported, together with appropriate quality flags, to the central database by the contributing network.

Users of wet deposition summaries have different requirements for the quality of the data. Regional scale deposition modelers, aquatic effects researchers and researchers concerned with long-term trend analysis may, therefore, have different criteria to determine if an individual measurement is valid. Regardless of these different criteria the steps, that must be addressed in preparing a useful data summary, are the same. These steps are (1) statement of intended use of the data summary, (2) selection of site representativeness criteria, (3) determination of valid sample screening criteria, (4) calculation of data completeness measures and assignment of data quality levels, (5) assignment of overall data quality level, and (6) specification of summary calculation procedures. Each of these steps are discussed in the context of the preparation of seasonal and annual summaries of wet deposition amounts intended for evaluating regional acid deposition models.

SITE REPRESENTATIVENESS

Most acid deposition monitoring networks have established criteria for selecting a site for incorporation into the network (e.g. Bigelow, 1984; Anderson, 1986). The concept of a site representativeness level differs from siting criteria, in that a site is evaluated according to the suitability of its inclusion into a summary. Hence, site representativeness levels are specific to the intended use of the summary.

Here, we assign a site representativeness level to each site. The levels distinguish between regionally representative, regionally unrepresentative, potentially regionally representative and potentially regionally unrepresentative sites. The criteria in Table 1 form the basis for assessing the site. Level 1 sites do not suffer from any of the interferences listed in the table and were considered to be regionally representative. On the other hand regionally unrepresentative, level 3, sites are sites subjected to local influences (e.g. dusty surroundings, significant emission sources within 40 km), which are known or strongly suspected to have a significant effect on seasonal/annual average wet deposition values. However, there are a number of sites, which fall neither into the 1 nor 3 categories. These sites were assigned to level 2. They failed on the

Table 1. Criteria to identify regionally representative sites

(1) No continuous industrial source, town or suburban area located within 10 km.
(2) No major point source (or combination of point sources) with emissions greater than 10,000 tons sulfur dioxide or nitric oxide per year located within 50 km.
(3) No surface pollutant storage facility (e.g. salt pile) located within 100 m.
(4) No transportation sources, furnaces or incinerators located within 100 m.
(5) No cultivation or other agricultural activity within 500 m.
(6) No buildings, trees, etc., impinge on the cone defined by a 45 degree angle above the horizontal plane and centered at the site (30 degrees is considered optimal, but 45 degrees is the highest acceptable angle).
(7) No local dusty conditions due to poor ground cover.

basis of one or more of the criteria in Table 1. The severity of the local influences, however, was difficult to assess *a priori*. Whenever possible, comments of individual network managers, analyses of historical data, or site audits were relied upon to distinguish further between level 2a and 2b sites. For the former, the local interferences were judged to be small and the sites were rated as potentially regionally representative (2a). Level 2b sites had more problems associated with them, although those familiar with their surroundings or historical data did not feel that they should clearly be assigned to a level 3 rating. They were nonetheless judged to be potentially regionally unrepresentative and data from them should be regarded with somewhat less confidence than data from level 2a sites.

VALID SAMPLE SCREENING FOR DATA SUMMARIZATION

Valid sample screening is defined as the selection of precipitation chemistry samples, taken at a site during a period, that can be used in the computation of average concentrations and deposition amounts for the site over the period. It includes determining if the chemical analysis of the sample as well as the characteristics of the sampling period meet specified criteria. For example, a sample SO_4^{2-} concentration may meet criteria that indicates that it represents the actual SO_4^{2-} concentration of the precipitation in the sample collector, but the collector may have failed resulting in a sample containing both wet and dry deposition.

Since the ADS only reports data from networks which have comprehensive quality assurance/quality control programs, the networks provide the validation of the chemical integrity of a sample. The following criteria define valid sample period for data summarization.

All sampling periods for which it is known that no precipitation occurred are considered valid sample periods. This applies mainly to weekly, monthly, and 28-day sampling protocols. For event and daily sampling protocols the absence of a sample record for a day implies that no precipitation and no wet deposition occurred. Hence, for purposes of data completeness measures, these samples are considered valid.

The wet deposition sample must be a wet-only sample. All samples identified as bulk, partially bulk or undefined are invalid. Bulk and undefined samples include contributions from dry deposition. Since wet deposition is of interest, these samples are declared invalid.

Wet deposition samples that have insufficient precipitation to complete a chemical analysis for a specific ion species are invalid for that specific species. For eastern North America, the total precipitation associated with these periods is small and hence the exclusion of these samples have minimal effect on seasonal/annual precipitation-weighted means and deposition amounts. The statistical distribution of the concentrations may, however, be distorted. For dry regions, such as the western U.S., the effect of excluding these samples is likely greater.

An individual ion species concentration, accompanied by a network comment (flag) designating the measurement to be 'suspect' or 'invalid', is considered an invalid sample. Deletion of the ion species concentration by a network for the same reason is similarly treated. Since the criteria for these codes vary among the networks, a standardization of these flags were required for the ADS.

The actual sampling period for a measurement sample must be close to a network's protocol sampling period. Specifically, the following leads to an invalid sample. For NADP/NTN (weekly sampling period), actual sample period <6 days or >8 days. For APIOS-C (28 day sampling period), actual sample period less than 21 or greater than 35 days. For CANSAP, actual sample period less than 22 or greater than 36 days.

The length of a collection period affects the representativeness of the concentration and composition of a sample and the comparability of concentrations across samples within a network. Different averaging periods affects the concentration and deposition probability density variance. Hence, restricting sampling periods to lengths close to the protocol period length is desirable.

The stringent criteria, used by the UDDC, restrict a valid sample period to periods, were the sample represents wet deposition only and contamination is minimized. These criteria may be relaxed in, e.g. effects research.

DATA COMPLETENESS MEASURES AND QUALITY LEVELS

Data completeness measures are based on the assumption that the entire season or year consists of sample periods that account for every day of the summary period. Normally a site, however, lacks information for some precipitation events during a summary period; temporarily deviates from established collection protocols; or collects samples that do not meet the quality assurance/quality control criteria of the network. Therefore, it is necessary to establish criteria to determine the number of samples that are required for calculation of meaningful seasonal or annual average concentration or deposition amount for a site. Five data completeness measures were selected: percent precipitation coverage length; per cent total precipitation; per cent valid sample length; per cent of samples with measured precipitation that are valid; and per cent collection efficiency. A sixth measure, per cent sea salt correction, is applied to sulfate summaries for sites within 100 km of a coast. The measures are defined in Table 2.

Table 2. Definition of data completeness measures

Data completeness measure	Definition
%PCL	Per cent precipitation coverage length (%PCL) is the per cent of the summary period for which information on whether or not precipitation occurred is available. If precipitation is known to have occurred during a particular sampling period but no measurement of the amount is available, then no knowledge of precipitation is assumed. Total precipitation depth TP is the amount of precipitation occurring during the period of precipitation coverage. This data completeness measure does not include any consideration of the availability of the valid precipitation chemistry sample.
%TP	Per cent total precipitation (%TP) is the per cent of the total precipitation depth measured during the summary period that is associated with valid samples.
%VSL	Per cent valid sample length (%VSL) is the per cent of the days during the summary period that are associated with valid samples periods. Note that sample periods with no precipitation are considered valid samples.
%VSMP	Per cent of wet deposition samples, that have valid sample concentration measurements.
%COLEFF	Per cent collection efficiency (%COLEFF) is the ratio (converted to per cent) of the total sample volume (converted to a depth) to the total precipitation depth, for qualifying samples, i.e. samples (a) that have both a co-located standard gauge and sample volume measurement available and (b) that have a valid sample concentration measurement.
%SEASALT	Per cent sea salt correction (%SEASALT) is the per cent of the average sulfate concentration that is estimated to be due to sea salt, using sodium or magnesium as tracers of sea salt.

The selection of measures were motivated by the following questions, which must be answered before the temporal representativeness of a datum can be assessed. For what portion of the summary period do we know the amount of precipitation that fell? What portion of the precipitation measured is associated with a valid chemical analysis and valid sample? What per cent of the time during the summary period do these valid samples represent? What per cent of the total number of actual sample periods with measured precipitation do these valid samples represent? What was the collection efficiency for valid samples, referred to a co-located standard gage, over the summary period? What percentage of the sulfate concentration is attributable to sea salt contamination at coastal sites? Each measure is assigned a rating 1–4 depending on its value (see Table 3).

The data completeness measures form the basis for assigning a data completeness level (1–4) to each seasonal and annual value (Table 3). Level 1 has the highest level of data completeness and hence the best information. Least confidence is given to a summary with data completeness level 3. Level 4 summaries are viewed as not providing representative values for the period and are not reported here. To assign a specific level to a seasonal or annual value, all criteria for that level must be met. The percentages used in Table 3 to determine the data completeness are based on the experience of the Committee. Preliminary studies, as discussed in the following section, indicate their significance.

The collection efficiency requirement for Canadian winter averages and totals are relaxed somewhat due to the generally poorer collector performance for snow sampling. If the criteria for other seasons were applied to winter months, when a large percentage of the precipitation in Canada is in the form of snow, then only a few locations would meet even the level 3 criterion. A lower percentage is accepted for winter, because it was felt the problems are primarily due to undercatch of snow. An under-collected snow sample is likely to represent the concentration, but underestimate the deposition amount.

The data completeness level for an annual value is based on annual criteria as well as criteria for the four quarters. These requirements ensure that adequate data from each quarter is present in the annual value. Some quarterly criteria, however, are less stringent than the seasonal criteria (see Table 3).

OVERALL DATA QUALITY LEVELS

The quality of a data summary is a function of the representativeness of a site and of the completeness of the data on which the summary is based. Data completeness includes considerations of the chemical integrity of the sample. In the previous sections site representativeness levels and data completeness levels were introduced as a means to assess the quality of the data summary. Here, the measures are combined to obtain a measure of the overall quality (error/uncer-

Table 3. Data completeness level criteria for seasonal and annual summaries

Data completeness measure	Seasonal data completeness level 1	2	3
%PCL	⩾95%	⩾90%	⩾90%
%TP, %VSL, %VSMP	⩾80%	⩾70%	⩾60%
%COLEFF			
Winter	⩾80%(50%)*	⩾60%(40%)*	⩾50%(30%)*
Spring, summer, autumn	⩾80%	⩾60%	⩾50%
%SEASALT	⩾25%	⩾50%	⩾75%

Data completeness measure	Annual data completeness level 1	2	3
%PCL			
Annual	⩾95%	⩾90%	⩾90%
Each quarter	⩾75%	⩾60%	⩾50%
%TP, %VSL, %VSMP			
Annual	⩾80%	⩾70%	⩾60%
Each quarter	⩾70%	⩾60%	⩾50%
%COLEFF			
Annual	⩾80%(70%)*	⩾60%(40%)*	⩾50%(30%)*
Winter	⩾80%(50%)*	⩾60%(40%)*	⩾50%(30%)*
Spring, summer, autumn	⩾80%	⩾60%	⩾50%
%SEASALT	⩾25%	⩾50%	⩾75%

*The bracketed value applies to Canadian sites.

Table 4. Overall data quality level

Site representativeness level	Data completeness level 1	2	3	4
1	1	2	3	4
2a	2	2	3	4
2	2	2	3	4
2b	2	2	3	4
3	3	3	3	4

tainty) of the average concentrations and deposition amounts at a site.

The overall data quality is divided into four levels as defined in Table 4. Level 1 data meets the most rigorous screening criteria, and hence is considered to be of the best quality and most suitable for model evaluation and trend analysis. On the other hand, level 3 represents what is judged to be the minimum acceptable quality for model evaluation.

The assignment of an overall data quality level is one of the novel features of the data summarization process presented here. This is the first step in an attempt to attach a quantitative level of confidence to a data summary. The present assignment of levels provides an ordinal ranking that qualitatively reflects different levels of confidence. Work is underway at a number of institutions that may allow quantitative estimates to be made in the near future.

Preliminary comparisons of seasonal and annual precipitation weighted mean concentrations and deposition amounts for co-located samplers during the period 1980–1984, reveal that the average per cent differences (defined as $200(A-B)/(A+B)$), maximum, minimum and median differences in concentrations and deposition amounts for sites with data completeness meeting level 1 criteria and with 100% PCL were roughly 25, 60, 0, 16 and 20, 60, 5 and 15%, respectively, for the twenty qualifying Canadian samplers. Comparable values for the 42 U.S. samplers were about 5, 35, 0, 3 and 15, 60, 0 and 5%, respectively. Based on only four samplers, meeting level 2, 3 criteria, the per cent average and maximum concentration differences were 45% and 60%, while the corresponding deposition differences were over 50 and 100% (UDDC unpublished). Table 5 show differences in annual and seasonal wet deposition amounts for co-located or closely located samples with an overall rating of 1 or 2, for the years 1980–1982 (Clark *et al.* 1987). Recently, Sirois (1990) studied the effect of missing precipitation (TP) and samples (VSMP) on estimated precipitation-weighted mean concentrations. He found that level 1, 2 and 3 criteria, i.e. %TP and %VSMP being ⩾80%, ⩾70% and 60%, respectively, lead to a seasonal absolute bias and standard deviation (bracketed) in estimated concentrations of 4(8), 7(11) and 14(15) per cent. Corresponding annual values were 6(4), 7(7) and 10(9) per cent. Seasonal expected maximum absolute difference for level 3 was estimated to over 50% (Table 6). In addition, Alvo and Voldner (1989) found that for co-located samplers with overall ratings of 1 or 2, the differences in annual deposition between the samplers could exceed the annual variation in deposition. This has implications for trend analysis.

Table 5. Differences in the seasonal and annual amounts of sulfur wet deposition (expressed as a per cent) at colocated or closely located samplers for 1980–1982

	Overall rating	Distance (km)	Number of pairs	Maximum % difference	Mean % difference
Annual	1	<1	1	8	8
(1980)	1	<90	2	26	17
	1 and 2	<1	3	11	9
	1 and 2	<90	7	27	13
Winter	1	<1	3	49	30
(1980)	1	<90	7	70	37
	1 and 2	<1	6	49	24
	1 and 2	<90	19	70	29
Spring	1	<1	2	13	11
(1980)	1	<90	7	54	17
	1 and 2	<1	4	19	15
	1 and 2	<90	15	54	24
Summer	1	<1	3	32	26
(1980)	1	<90	10	59	28
	1 and 2	<1	7	32	19
	1 and 2	<90	20	70	21
Autumn	1	<1	2	13	7
(1980)	1	<90	8	44	24
	1 and 2	<1	5	35	19
	1 and 2	<90	42	99	33
Annual	1	<1.1	5	12	9
(1981)	1	<26	11	44	19
	1 and 2	<1.1	9	13	8
	1 and 2	<26	27	44	26
Annual	1	<1.1	7	15	7
(1982)	1	<26	15	37	10
	1 and 2	<1.3	13	39	16
	1 and 2	<26	34	65	18

SUMMARY CALCULATION PROCEDURES

Preparation of annual and seasonal data summaries requires definitions of annual periods and seasons. Annual periods are selected to coincide as closely as possible with the calendar year. Seasons are defined to follow the climatological seasons: winter—December, January, February (contiguous); spring—March, April, May; etc.

Some networks use collection periods that do not necessarily coincide with the preferred annual and seasonal periods. The overlapping collection period is, therefore, allocated to a summary period on a fractional time basis (UDDC, 1985, 1986). The first and last date of the actual period summarized is noted in the data summary.

Estimates of precipitation depth for each collection period and of total precipitation during the summary period are required for computation of concentrations and total wet deposition amounts. Precipitation (referred to as standard gage depth), recorded at a site by a rain gage co-located with the collector, is generally used in the calculations. Deviations from this practice occurs, when the rain gage value is missing or the collector experiences catch efficiencies greater than 110% (UDDC, 1985, 1986).

Summary statistics are based only on collection periods that meet the stated valid sample screening criteria. Valid samples with concentrations, identified as below the detection limit by a network, are included in the data summary although the way they are handled depends on the statistic calculated (UDDC, 1985, 1986).

Precipitation-weighted mean concentration is calculated as:

$$\bar{C} = \sum_{i=1}^{n} C_i P_i / \sum_{i=1}^{n} P_i$$

where $\bar{C}$ is the precipitation-weighted concentration for the summary period, C_i is the ion concentration, P_i is the precipitation depth measured for the ith collection period, and n is the number of simultaneous valid sample measurements of precipitation and ion concentration during the period.

Seasonal and annual deposition amounts are calculated as the product of the precipitation-weighted concentration and the total precipitation for the season or year. Specifically:

$$D = \bar{C} \times TP \text{ and } TP = \sum_{i=1}^{N} P_i$$

where TP is the total precipitation and N is the number of collection periods with available precipitation depth. Note that if a precipitation depth and a valid chemistry sample are available for every collection period when precipitation occurred, then the

Table 6. Estimates of the expected absolute relative bias, standard deviation, maximum and minimum concentration differences (%) for sulfate for the three UDDB data completeness criteria

Level	Period	|Bias| %	St. dev. %	Minimum %	Maximum %
1 (TP and VSMP)	Seasonal	<4	<8	−35	22
⩾ 80%	Annual	<6	<4	−23	15
2 (TP and VSMP)	Seasonal	<7	<11	−44	40
⩾ 70%	Annual	<7	<7	−32	23
3 (TP and VSMP)	Seasonal	<14	<15	−53	55
⩾ 60%	Annual	<10	<9	−37	35

deposition is simply the sum of the deposition occurring during each collection period. If a precipitation depth is available for every collection period, but the concentration of the ions are missing (or invalid) for one or more collection periods, then the procedure is equivalent to the assumption that concentration values are equal to the precipitation-weighted concentration based on the available data for all collection periods.

RESULTS AND DISCUSSION

The main objective of this study was to prepare quality controlled seasonal and annual summaries of precipitation chemistry data from five major acid deposition monitoring networks in North America. In addition to precipitation-weighted mean concentrations and wet deposition amounts at each site, statistics for concentrations measured at each site were computed. The statistical measures include: minimum and maximum values; means (arithmetic and geometric); the 25th, 50th and 75th percentiles; and the Kolmogorov–Smirnov *D*-statistic to test the distribution of the data for normality and log normality. Due to space limitations, it is not possible to present the total data set here. Hence, only sulfate wet deposition values will be discussed. The reader is referred to the original report for 1980 and an addendum for 1980–1983 by the UDDC (1985, 1986). Further, Olsen and Watson (1984), Olsen and Slavich (1985, 1986), and Sweeney and Olsen (1987, 1989) published data summaries for 1980–1986. These summaries are available in either hard copy or computerized form from the ADS database.

Examples from the 1984 data summary are shown in Tables 7 and 8. Table 7 lists by station the annual sulfate concentration and deposition amounts, as well as the overall data quality levels (the individual siting and data completeness ratings on which the overall levels are based). If the datum qualified for a sea-salt correction, then the corrected concentration and deposition amounts are shown below the uncorrected ones. The number of collection periods (N) used and number of valid samples where measurements are below the detection limit (NBDL) are also shown. The statistical quantities are displayed in Table 8.

The data quality levels at each site in the area of interest for 1984 are shown in Fig. 1. Different symbols are used to designate the levels 1–4 quality data (squares, filled circles, triangles and open circles).

The geographic distribution of sites, operating during the entire year, and their site representativeness level is shown in Fig. 2, while the data completeness levels are shown in Fig. 3. Table 9 gives, for each network, the number of sites operating the full year and the number of sites that met the overall data quality reporting criteria for annual sulfate summaries for the years 1980–1986. From 1980–1986, the number of sites increased from 108 to 290, primarily due to the expansion of the NADP/NTN. In 1983 several of the CANSAP sites were converted to the CAPMoN, resulting in the reduction of sites in the former network. The sites, meeting level 3 criteria or better, increased from 50% in 1980 to 67% in 1986. The increase reflects elimination of start-up problems and improvements in network management.

Sites that operated a full year in 1984 are categorized by site representativeness level and data completeness level for sulfate deposition, as shown in Table 10. Excluding CANSAP, for which data were not available, 232 sites operated at some time during 1984 and 154 (66%) met the minimum overall data quality level. Of the 154 sites with an overall data quality level of 3 or less, only 14 (9%) are level 1, 94 (61%) are level 2, and 46 (30%) are level 3. Over 80 per cent of the sites are regionally representative or potentially regionally representative. This reflects the care used in selection of location for the more recent sites.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A framework has been provided for assessment of data quality based primarily on four considerations: the potential for contamination of the sample by

Table 7. Example table for annual summary of sulfate precipitation chemistry concentration and deposition

1984 Annual Data Summary
Derived from the Acid Deposition System (ADS) Database
3-Aug-1988
Page 5

Sulfate

State / Network / Site Name	Period Summarized First Date	Last Date	Overall Rating	Site Rep	Data Comp	% PCL	% TP	% VSL	% VSMP	% Col Eff	N	N BDL	Wtd Mean ueq/l	SO4 Dep g/m2	% Sea Salt Corr.	Total Precip cm
Vermont																
NADP/NTN																
Bennington	Jan 3 84	Jan 2 85	2	2A	2	100	91	92	94	95	45	2	2.24	2.56		113.9
UAPSP																
Underhill Center	Jan 1 84	Jan 1 85	2	2A	1	100	100	99	98	96	129		2.21	2.33		105.4
Virginia																
NADP/NTN																
Horton's Station	Jan 3 84	Jan 2 85	3	3	3	100	77	71	83	95	33		2.01	2.12		105.3
MAP3S/PCN																
Virginia	Jan 1 84	Jan 1 85	2	2A	2	99	96	95	77	121	58		1.99	2.12		106.1
Washington																
NADP/NTN																
Olympic Nat. Park	Jan 3 84	Jan 2 85	2	2A	2	100	88	88	85	95	44	5	.35	1.28		348.8
													.24	.83	21	
West Virginia																
NADP/NTN																
Babcock State Park	Jan 3 84	Jan 2 85	2	2A	1	100	95	92	92	99	48		2.22	2.78		125.1
Parsons	Jan 3 84	Jan 2 85	2	2B	1	100	100	94	94	93	47		2.46	3.45		140.3
Wisconsin																
NADP/NTN																
Lake Dubay	Jan 3 84	Jan 2 85	2	2B	1	100	98	85	84	98	41		1.99	1.62		81.3
Spooner	Jan 3 84	Jan 2 85	1	1	1	100	99	88	87	9%	48	1	1.46	1.17		80.1
Trout Lake	Jan 3 84	Jan 2 85	2	1	2	100	86	79	80	93	39		1.44	1.16		80.2
American Samoa																
NADP/NTN																
American Samoa	Jan 3 84	Jan 2 85	2	2	1	100	98	98	98	97	46		.82	2.13		258.7
New Brunswick																
CAPMoN																
Harcourt	Jan 1 84	Jan 1 85	1	1	1	100	95	95	88	94	143	1	1.24	1.68		135.8
													1.16	1.58	7	
Newfoundland																
CAPMoN																
Bay d'Espoir	Jan 1 84	Jan 1 85	1	1	1	100	95	96	91	89	151		.94	1.58		165.3
													.81	1.34	13	
Goose Bay	Jan 1 84	Jan 1 85	3	2B	3	100	98	78	83	88	133		.85	.88		93.9
													.81	.76	6	
Nova Scotia																
CAPMoN																
Jackson	Jan 1 84	Jan 1 85	1	1	1	100	95	91	82	91	158		1.17	1.81		154.5
													1.05	1.63	10	
Kejimkujik (b)	Jan 1 84	Jan 1 85	2	1	2	100	99	98	98	97	149		1.28	1.68		131.5
													1.13	1.49	15	
Ontario																
CAPMoN																
Chalk River	Jan 1 84	Jan 1 85	2	2A	2	100	88	98	78	92	121		2.78	2.32		88.2
Dorset	Jan 1 84	Jan 1 85	3	1	3	100	89	83	88	91	134		2.57	2.58		104.1
ELA (b)	Jan 1 84	Jan 1 85	3	2A	3	100	94	89	71	87	101		1.27	.78		61.8
Longwoods (a)	Jan 1 84	Jan 1 85	2	2B	1	100	97	96	90	97	112		3.62	3.61		99.6
APIOS-D																
Balsam Lake	Jan 1 84	Jan 1 85	2	1	2	100	94	91	79	90	115		2.75	2.49		90.5
Charleston Lake	Jan 1 84	Jan 1 85	2	2A	2	99	94	96	88	81	93		2.36	1.98		83.7
Dorset (b)	Jan 1 84	Jan 1 85	3	1	3	100	95	82	67	94	128		2.27	2.32		101.9
Longwoods (b)	Jan 1 84	Jan 1 85	3	2B	3	99	91	93	80	89	91		3.61	3.48		96.4

Note: The annual data completeness level also depends on the quarterly data completeness levels

dryfall has been minimized by including only wet collector data; the laboratory, which has performed the chemical analysis of the measurements, is reputable and has judged the analysis to be valid; the site is (or is not) regionally representative; and the data are (or are not) sufficiently complete to have a high degree of confidence associated with the derived seasonal or annual values.

While few scientists familiar with deposition monitoring would dispute the above considerations are among the major factors involved in an assessment of the quality of wet deposition data, there are other questions that have not been addressed—for example, what is the magnitude of the errors introduced by field evaporation losses from cumulative samplers, or by chemical transformations, which may occur between the time of sample collection and chemical analysis? Some of these questions, however, are addressed indi-

Table 8. Example table for annual summary of sulfate precipitation chemistry concentration distribution

1984 Annual Data Summary
Derived from the Acid Deposition System (ADS) Data Base

2-Mar-1987
Page 5

Sulfate

State / Network / Site Name	Over All	Site Rep	Data Comp	N	N BDL	Wtd Mean mg/l	Geometric Mean mg/l	Geometric SD mg/l	Arithmetic Mean mg/l	Arithmetic SD mg/l	Concentration Percentiles mg/l Min	25%	50%	75%	Max	K-S D-Statistic Gau	K-S D-Statistic Log
Virginia																	
NADP/NTN																	
Horton's Station	3	3	3	33		2.81	2.84	2.89	2.81	1.81	.43	1.82	2.5	3.5	7.9	.137	.138
MAP3S/PCN																	
Virginia	2	2A	2	58		1.99	2.03	1.99	2.57	2.07	.38	1.32	2.1	2.7	10.6	.258•	.128
Washington																	
NADP/NTN																	
Olympic Nat. Park	2	2A	2	44	5	.35	.38	2.80	.68	.96	.10	.29	0.5	0.6	6.4	.359•	.139•
West Virginia																	
NADP/NTN																	
Babcock State Park	2	2A	1	46		2.22	2.17	2.08	2.86	2.40	.67	1.28	2.0	3.2	9.5	.222•	.109
Parsons	2	2B	1	47		2.46	2.40	1.88	2.88	1.75	.53	1.54	2.5	3.8	8.3	.164•	.078
Wisconsin																	
NADP/NTN																	
Lake Dubay	2	2B	1	41		1.99	1.99	1.63	2.25	1.21	.84	1.40	1.8	2.8	5.3	.176•	.111
Spooner	1	1	1	48	1	1.46	1.55	1.84	1.84	1.12	.43	1.05	1.6	2.5	8.1	.107	.083
Trout Lake	2	1	2	39		1.44	1.38	2.03	1.61	1.09	.17	.99	1.3	2.4	5.6	.208•	.121
American Samoa																	
NADP/NTN																	
American Samoa	2	2	1	46		.82	.99	2.84	1.51	3.03	.33	.61	0.9	1.4	21.1	.352•	.113
New Brunswick																	
CAPMoN																	
Harcourt	1	1	1	143	1	1.24	1.19	2.07	1.88	1.72	.01	.66	1.2	2.3	11.0	.217•	.062
Newfoundland																	
CAPMoN																	
Bay d'Espoir	1	1	1	151		.94	.95	2.39	1.40	1.37	.06	.48	0.9	1.9	8.5	.105•	.048
Goose Bay	3	2B	3	133		.05	.78	2.44	1.13	1.07	.04	.42	0.8	1.4	5.9	.171•	.042
Nova Scotia																	
CAPMoN																	
Jackson	1	1	1	158		1.17	1.40	2.53	2.19	2.73	.17	.70	1.5	2.7	25.5	.230•	.065
Kejimkujik (b)	2	1	2	149		1.20	1.44	2.41	2.10	2.41	.22	.76	1.3	2.7	17.2	.215•	.047
Ontario																	
CAPMoN																	
Chalk River	2	2A	2	121		2.70	2.32	2.38	3.21	2.56	.18	1.27	2.5	4.6	15.6	.143•	.067
Dorset	3	1	3	134		2.57	2.70	2.11	3.54	2.90	.33	1.64	2.8	4.5	19.0	.104•	.042
ELA (b)	3	2A	3	101		1.27	1.15	2.34	1.62	1.49	.14	.64	1.3	1.9	6.9	.101•	.074
Longwoods (a)	2	2B	1	112		3.62	3.41	2.02	4.25	2.83	.48	2.25	3.7	5.7	17.2	.106•	.078
APIOS-D																	
Balsam Lake	2	1	2	115		2.75	2.10	2.33	2.91	2.53	.15	1.20	2.1	3.4	12.0	.101•	.048
Charleston Lake	2	2A	2	93		2.36	2.05	2.70	3.17	3.21	.20	.90	2.1	4.2	22.4	.177•	.092
Dorset (b)	3	1	3	128		2.27	2.02	2.00	2.95	2.55	.10	1.23	2.1	3.9	12.0	.104•	.085•
Longwoods (b)	3	2B	3	91		3.01	3.07	2.30	4.99	4.24	.15	2.25	3.9	6.1	23.0	.190•	.067
Melbourne	2	2A	1	98		3.66	2.99	1.90	3.55	1.94	.35	1.97	3.4	4.7	8.5	.080	.080
Nithgrove	2	1	2	115		2.27	1.99	2.30	2.76	2.29	.20	1.20	2.0	3.5	12.0	.103•	.085•
Railton	2	1	2	54		2.33	2.00	2.06	2.60	1.58	.30	1.24	2.4	3.6	6.5	.122•	.100
Raven Lake	2	1	2	120		2.00	2.11	2.44	3.12	3.23	.15	1.23	2.1	3.6	20.5	.200•	.055
Wellesley	3	2B	3	99		2.96	2.59	2.32	3.67	4.00	.15	1.50	2.7	4.1	31.5	.222•	.060
APIOS-C																	
Alvinston	3	2A	3	11		3.95	3.67	1.50	3.94	1.51	1.90	2.50	3.7	5.1	6.0	.103	.127
Azure Lake	3	1	3	11		2.14	2.06	1.64	2.31	1.20	1.00	1.55	1.7	3.3	4.4	.224	.173
Bear Island	2	2A	2	11		3.13	2.65	1.79	3.01	1.35	.95	1.45	3.4	3.9	5.0	.178	.254•
Colchester	2	2A	2	12		4.45	4.27	1.45	4.53	1.55	2.05	3.11	4.4	5.0	7.2	.104	.118
Coldwater	2	1	2	12		2.96	2.70	1.59	2.97	1.35	1.20	1.76	2.9	3.0	5.9	.119	.097

Note: The annual data completeness level also depends on the quarterly data completeness levels

rectly by the data quality rating scheme proposed here. A cumulative sample with serious evaporation losses, would have a low collection efficiency, and hence would tend to get a lower quality rating. Other questions (such as chemical transformation) are beyond the scope of the study. Thus, while the present procedures are largely based on the Committee's understanding of precipitation sampling and chemistry and may require further revision, or indeed may not necessarily be the best for all users (e.g. those interested in environmental assessment may accept less stringent criteria), we recommend that the current effort will provide a point of reference for future work, and that, should alternative screening and calculation procedures be used, reasons will also be documented for departing from the present ones.

The Committee recommends that, for purposes of model evaluation on a seasonal or annual basis, the ADS data summaries be used. Furthermore, it is recommended that the procedures discussed here will

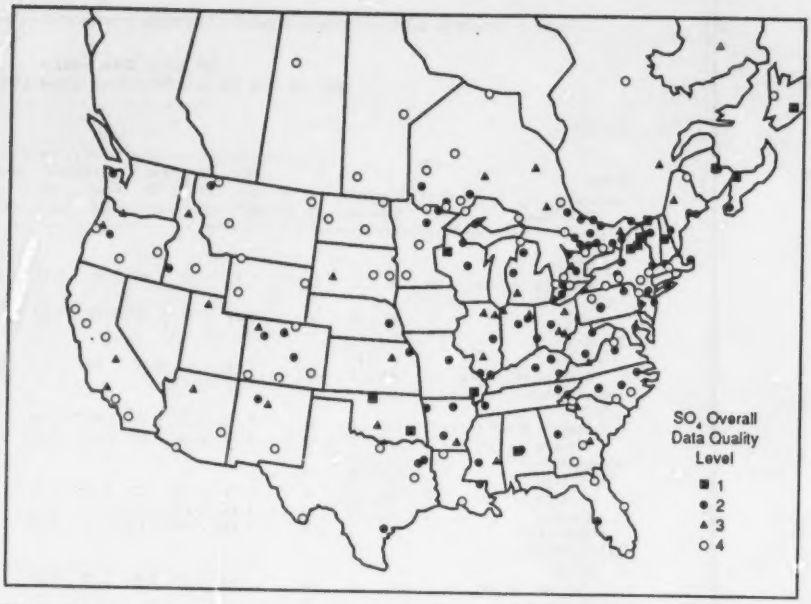

Fig. 1. Overall data quality levels associated with 1984 annual sulfate summaries for North American sites operating a full year in 1984. Level 4 summaries do not meet annual reporting criteria.

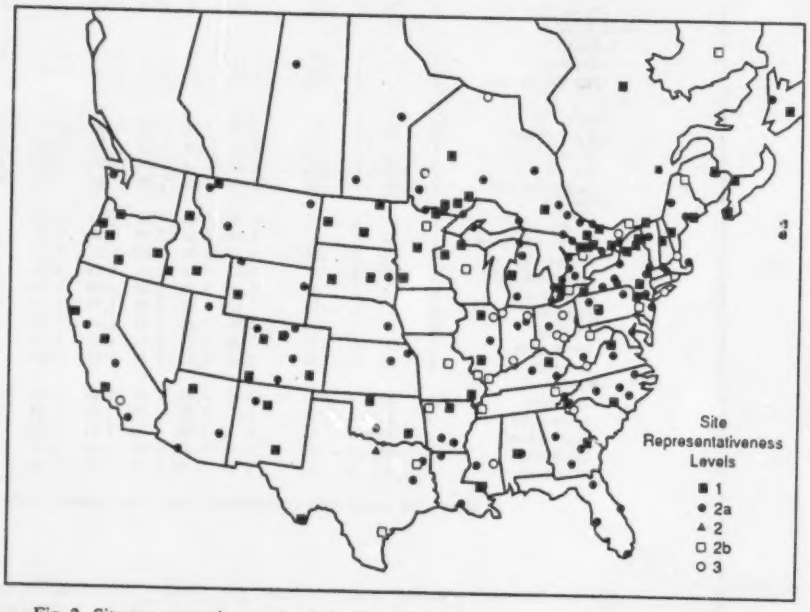

Fig. 2. Site representativeness levels for North American sites operating a full year in 1984.

be adopted by others having similar needs in the future, as the use of a unified and well-documented data set should simplify the task of scientists involved in the development of long-range transport models and emission reduction scenarios. It should be noted that concurrent in time when this work was completed, the NADP (1985, 1986a,b) and later NAtChem (1987) began producing annual summaries using essentially these procedures. In addition, ADS data were used in the ISDME (Voldner *et al.*, 1988; Clark *et al.*, 1989) and for analysis of spatial and temporal variability in acidifying species (e.g. Alvo and Voldner, 1989; Olsen, 1988; NAPAP, 1987; Seilkop and Finkelstein, 1987).

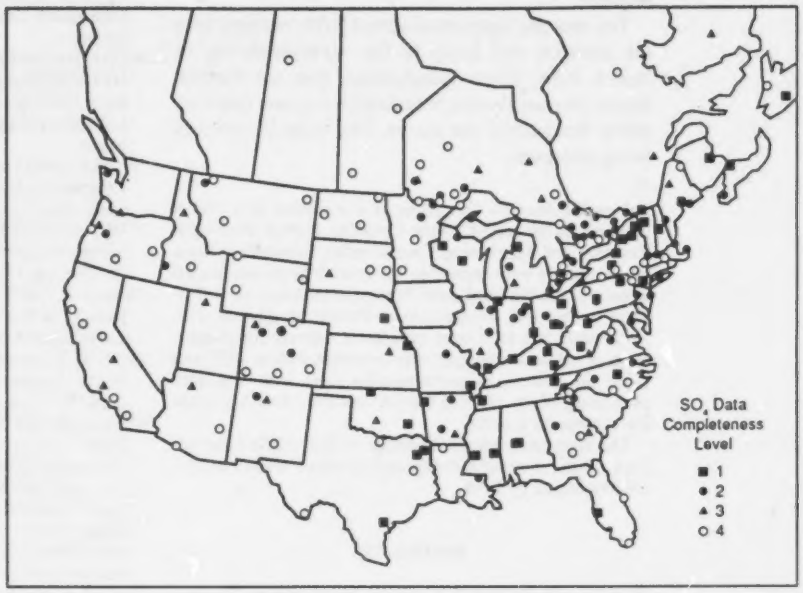

Fig. 3. Data completeness levels associated with 1984 annual sulfate summaries for North American sites operating a full year in 1984. Level 4 summaries do not meet annual reporting criteria.

Table 9. Number of sites in 1980–1986, operating a full year and meeting the minimum overall data quality level as a function of network

	Number of sites operating full year							Number of sites with overall data quality level ⩾3						
Network	80	81	82	83	84	85	86	80	81	82	83	84	85	86
NADP/NTN	36	73	89	102	138	179	187	26	53	60	71	85	101	115
MAP3S/PCN	8	9	9	9	9	9	9	7	8	9	8	9	9	9
UAPSP	6	6	21	20	19	21	24	6	5	21	20	18	19	21
APN*	4	6	7	1	1	1	—	2	5	5	0	0		*
APIOS-D	0	12	16	16	14	14	13	0	0	0	10	10	11	11
APIOS-C	0	30	33	32	34	32	36	0	10	14	22	21	20	22
CANSAP	54	57	54	30	—	—	—	13	20	15	6	—	—	—
CAPMoN	—	—	—	7	17	18	21	—	—	—	4	11	11	17
Total	108	193	229	217	232	274	290	54	101	124	141	154	171	195
Per cent meeting reporting criteria								50%	52%	54%	65%	66%	62%	67%

*APN sites which became CAPMoN sites in 1983 are included in CAPMoN's figures for 1983 and 1984.

Table 10. Number of sites meeting each site representativeness level and data completeness level for 1984 sulfate annual summaries

Site representative level	Data completeness level 1	2	3	⩾3	4	Total
1	14	21	16	51	30	81
2a	22	29	15	66	39	105
2	2	—	—	2	2	4
2b	15	4	3	22	5	27
3	5	6	1	12	3	15
Total	58	60	35	153	79	232

The concept of overall data quality levels, including site representativeness and data completeness levels, are considered essential to report with future data summaries. Work must continue to refine assignment of a site representativeness criteria, data completeness measures and level criteria. Although efforts have been made to quantify the errors/uncertainties in the concentration and deposition amounts, associated with

the different levels of data quality, more work is required.

The new site representativeness levels assigned here are tentative and apply to the situation during or before 1984. These assignments, and the criteria, should be re-evaluated periodically to ensure that they reflect the current site status. This issue is currently being addressed.

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The recommendations discussed in this article have not been subjected to EPA review and therefore are not necessarily endorsed by EPA.

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